HQE PMT – measurements of noise rate work in progress

HQE PMT now in use for IceCube's Deep Core

Measurements on R7081-02

Very recent (until last week) measurements on HQE PMT

FNAL, July 2009

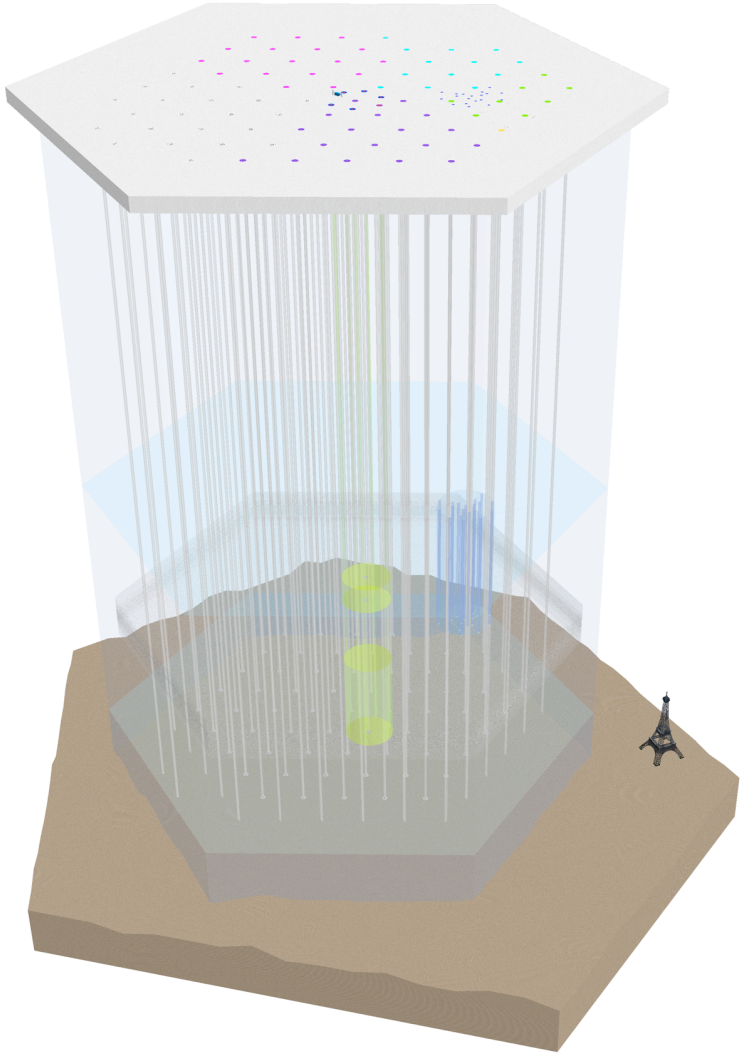
A. Karle, UW-Madison

Thanks to:

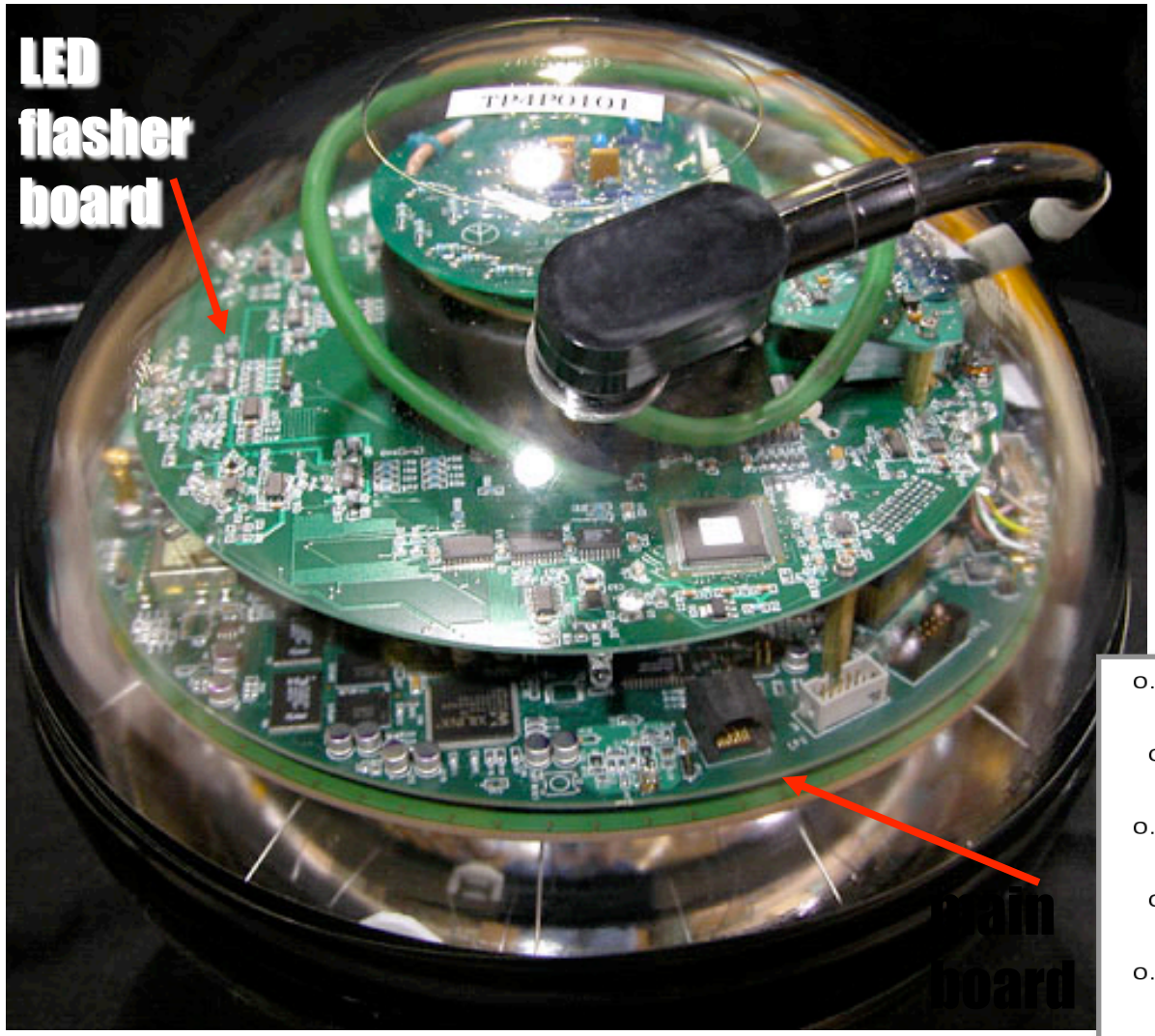
L. Gladstone, R. Maruyama, Ch. Wendt, N. Whitehorn

The IceCube Detector: current state

- 19 strings/stations installed during the 2008-2009 austral summer, commissioning ongoing
- Total of 59 strings and 118 IceTop tanks → over two thirds complete!
- Switching from 40 to 59 string operation in April



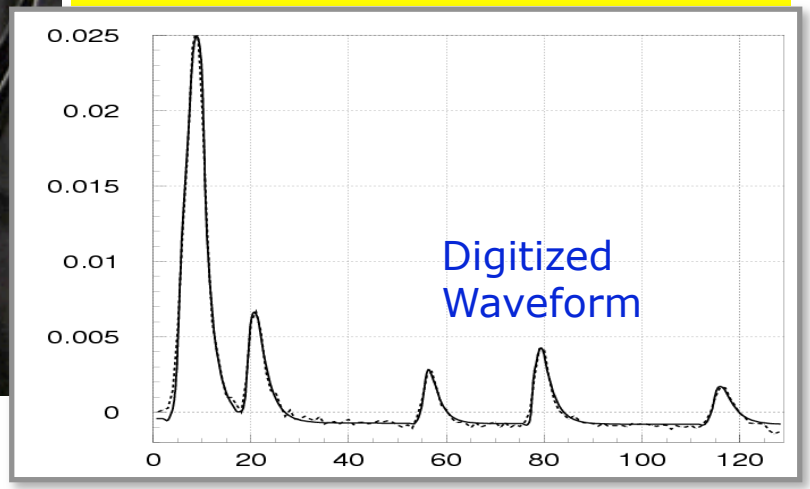
Digital Optical Module (DOM)



PMT: 10 inch Hamamatsu
Power consumption: 3 W
Digitize at 300 MHz for 400 ns with custom chip
40 MHz for 6.4 μs with fast ADC
Dynamic range 500pe/15 nsec

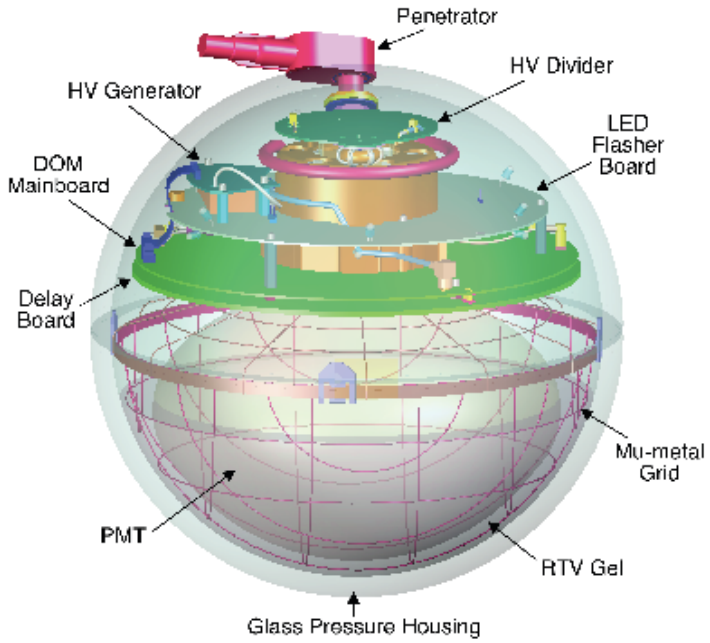
Send all data to surface over copper
2 sensors/twisted pair.
Flasherboard with 12 LEDs
Local UV

Clock stability: $10^{-10} \approx 0.1$ nsec / sec
Synchronized to GPS time every ≈10 sec
Time calibration resolution = 2 nsec



78 high quantum efficiency 10”PMT successfully tested for use in IceCube

- More than 4000 sensors with standard 10” PMT (R7081-02) integrated and tested in IceCube
- 78 high quantum efficiency PMT (10”) tested with IceCube standard production test program.
- Result:
  - Quantum efficiency ~38% higher (405 nm, -40C)
  - No problems found
  - Low temperature (-40C) noise behavior scales with quantum efficiency as expected.
- Deployed all modules in the ice this past season



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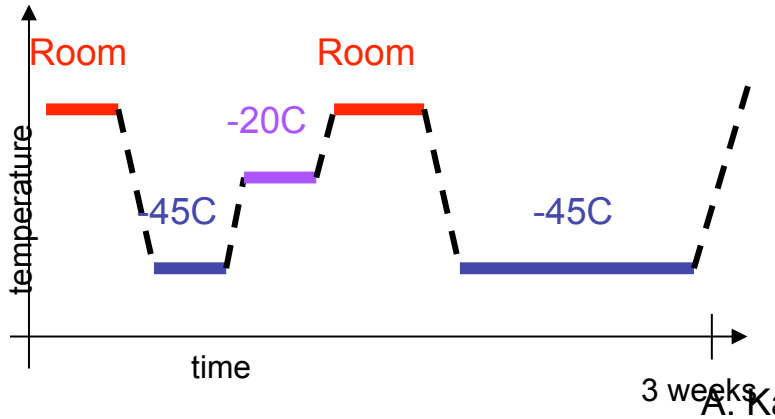
Dark Freezer modules

PMTs were run through standard final acceptance tests for IceCube

- Mass production tests
- All sensors are tested for 3 weeks for various parameters

Testing Temperature Profile

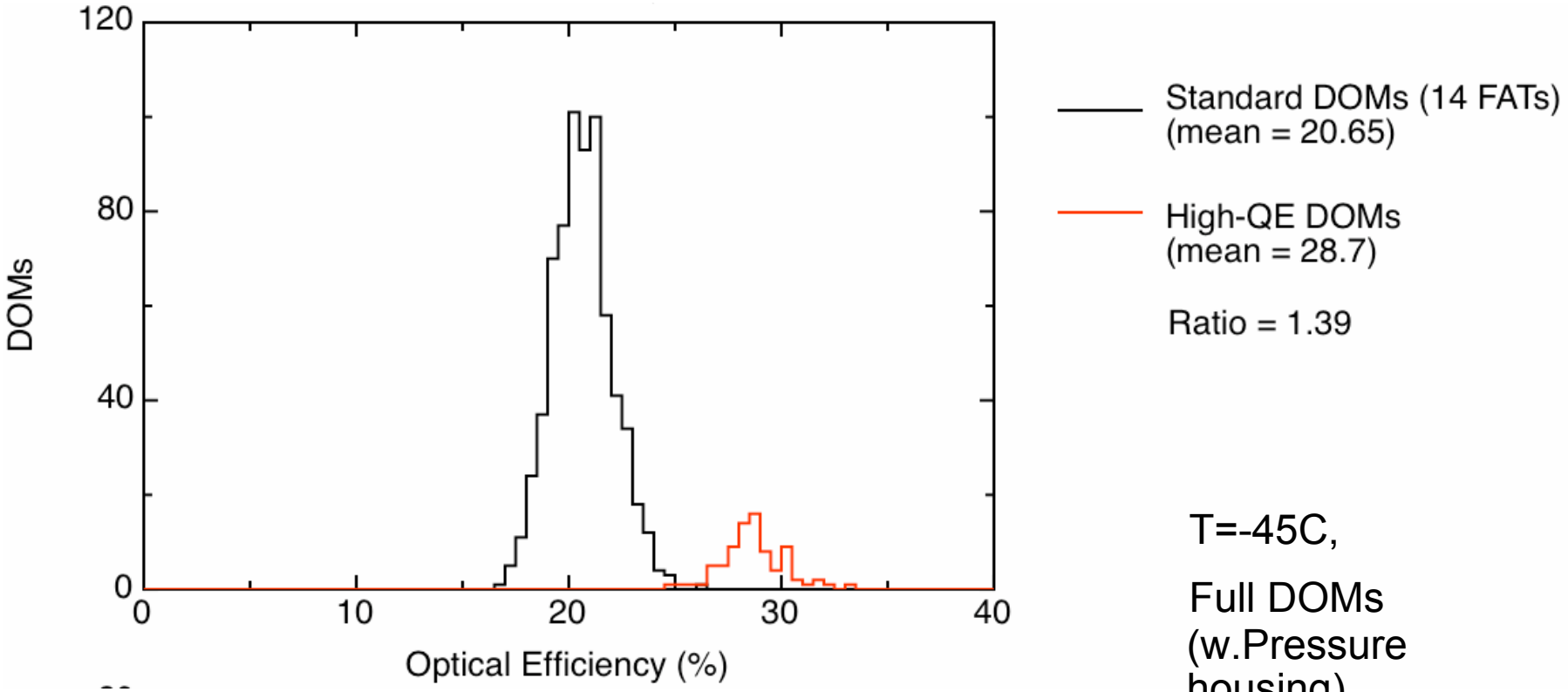


Testing Setup

Hamamatsu R7081-02 (standard IceCube, conventional cathode)

- Diameter: 10’’ (hemispherical)
- Cathode: Standard Bialkali
- Quantum efficiency: ~25% at 420 nm
- Dynodes: 10 (selected over 12 stage and another version)
- Gain: 10^7

Relative optical efficiency of sensors
(High QE versus super-bialkali: ~1.35)



T=-45C,

Full DOMs (w.Pressure housing)

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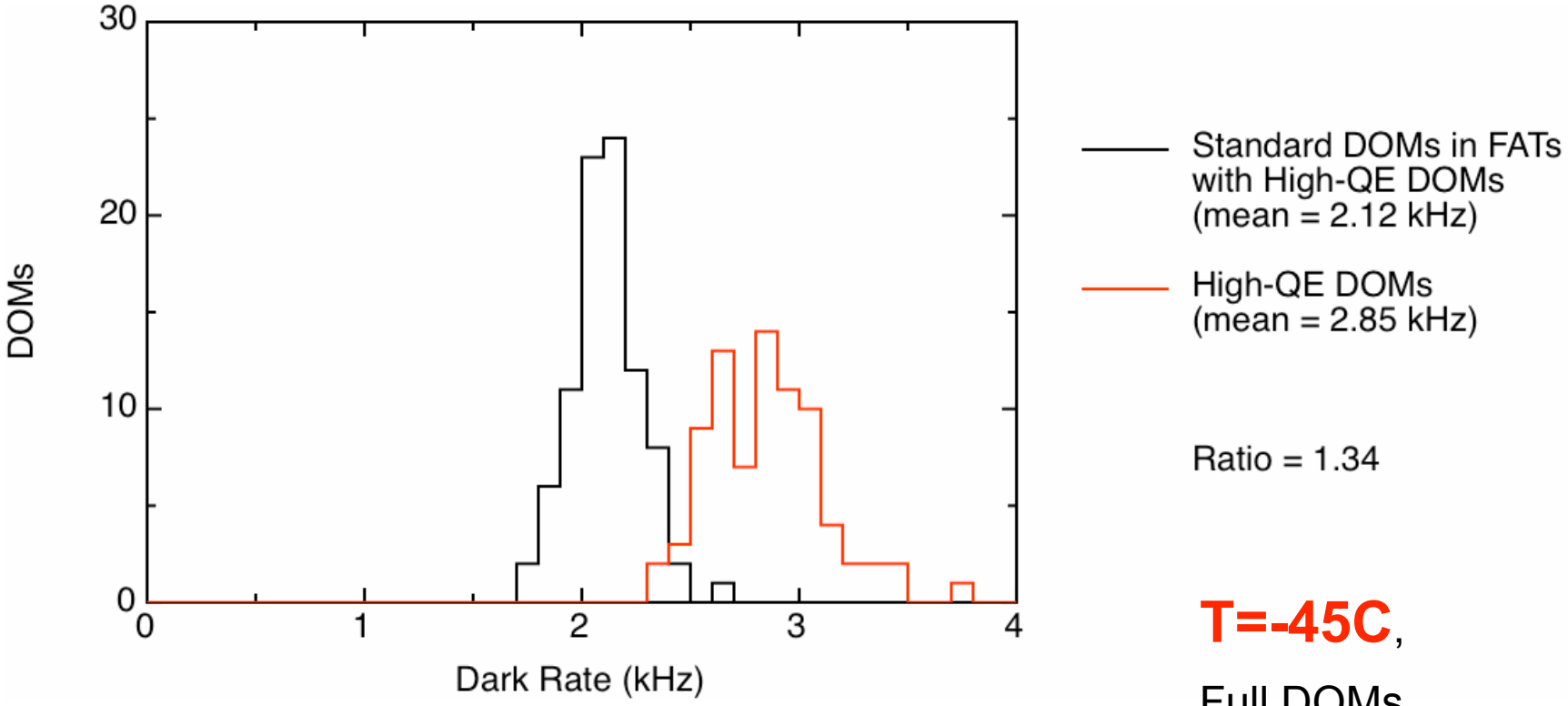
Noise rates of sensors at -45°C

conventional vs high QE



T=-45C,

Full DOMs (w.Pressure housing)

What is the rate at high temperature?

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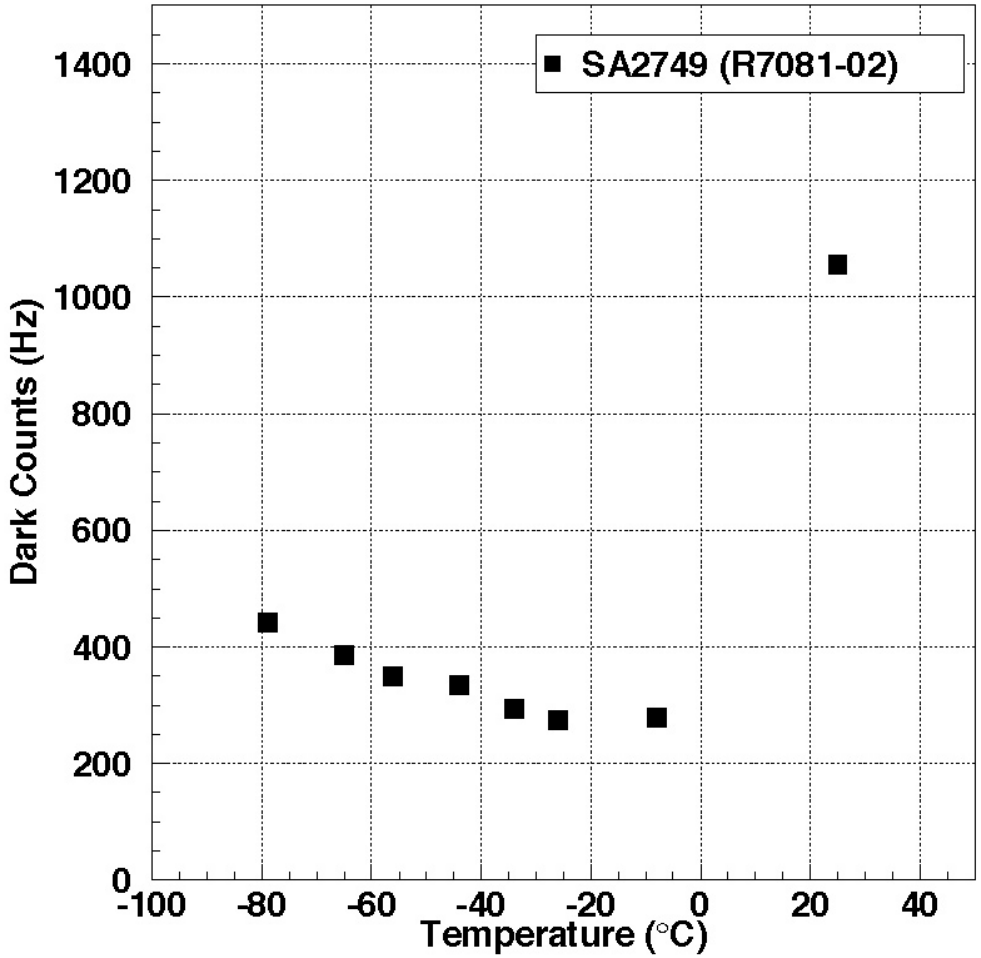
Noise rate versus temperature - conventional cathode

- Minimum noise level: ~300 Hz at ~-10C

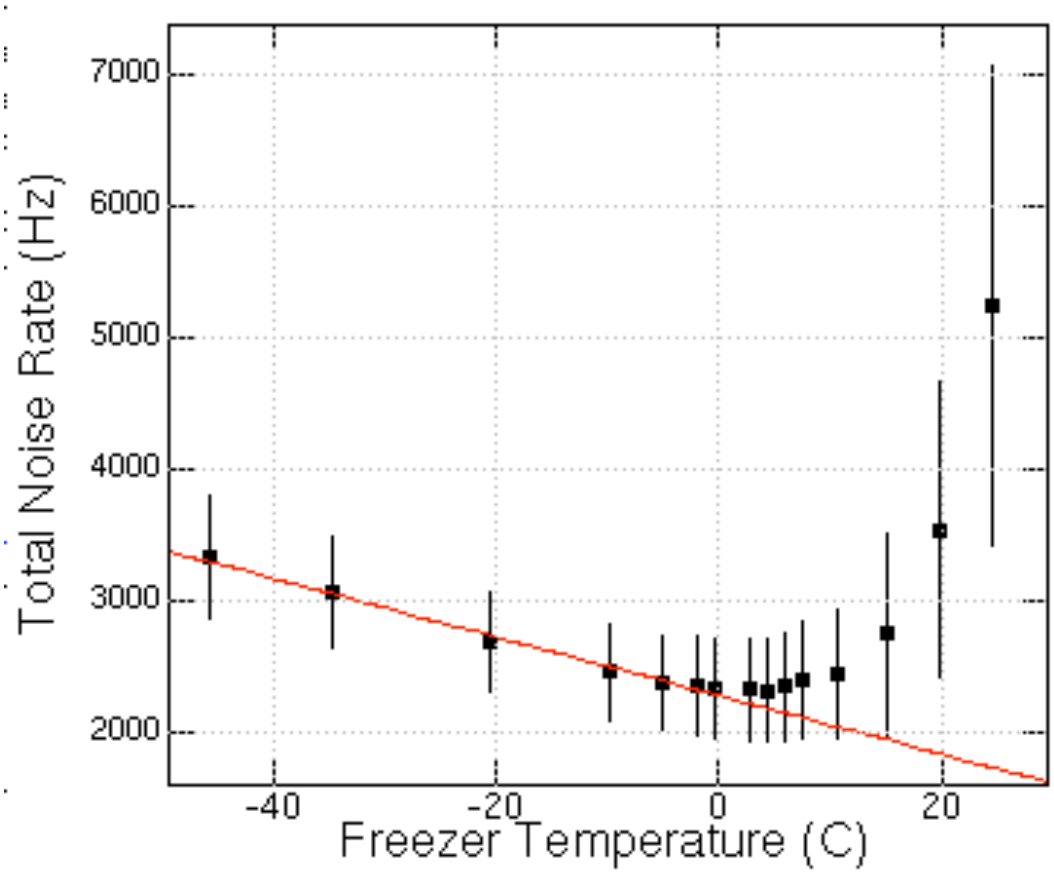


Noise vs temperature

- Measurements have been made of the noise rate of the integrated sensor, not the PMT.
- The resulting data are upper limits and at low temperatures they are dominated by noise from the glass pressure housing.
- Provide a pretty good estimate on the PMT noise dependence on temperature once the glass noise is subtracted.

Noise vs temperature

- At low temperatures the noise rates are dominated by the glass scintillation (red line) of pressure housing (~85%) and glass of PMT (15%).
- Glass noise of PMT only, at high temperature ~400 Hz
- Thermionic emission dominates at high temperatures



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Noise vs temperature of integrated DOMs (DOM=IceCube Digital optical modules with high QE 10 inch PMTs)

plots

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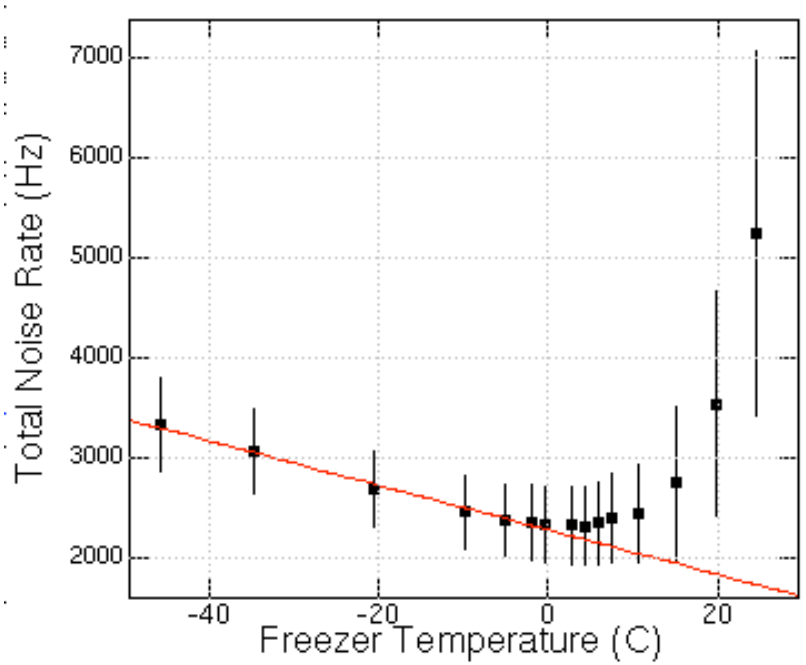
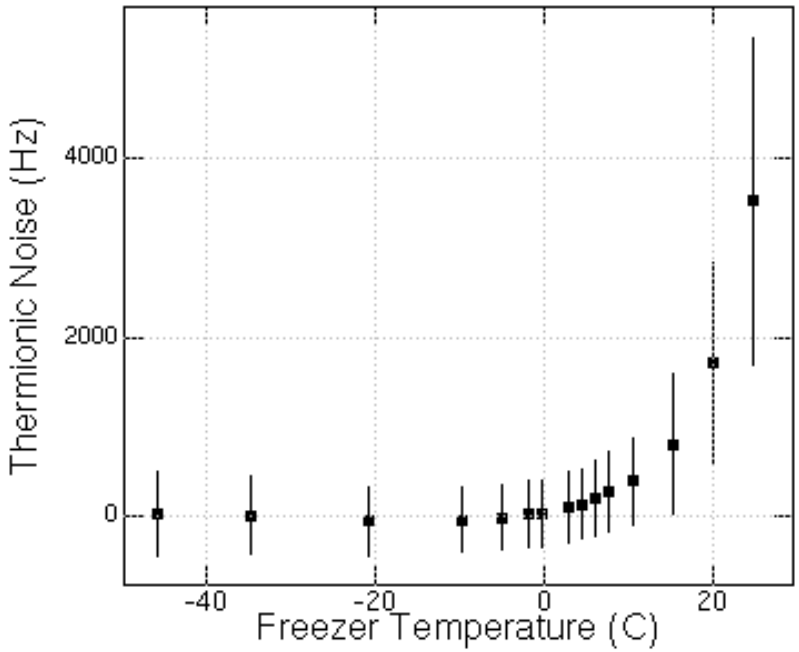
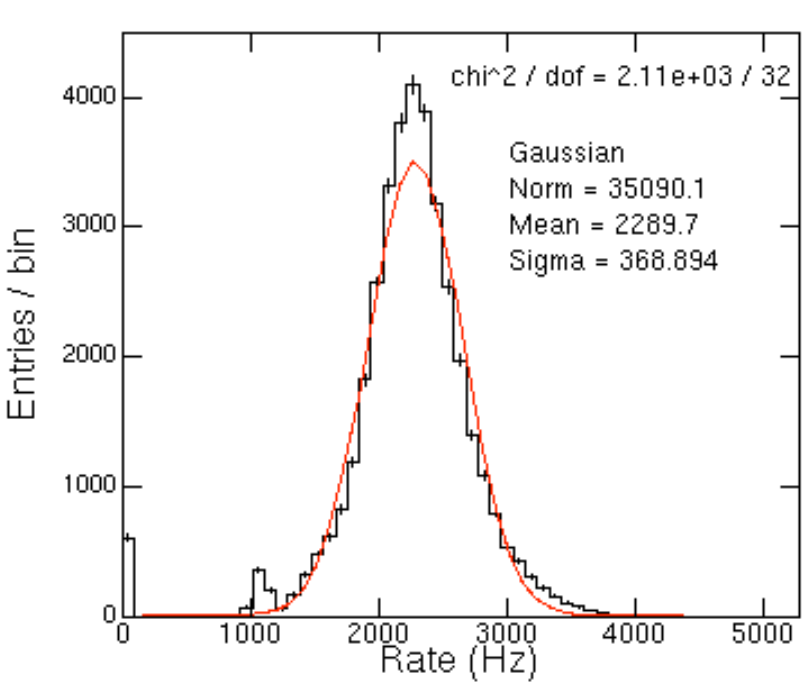
2 components of noise

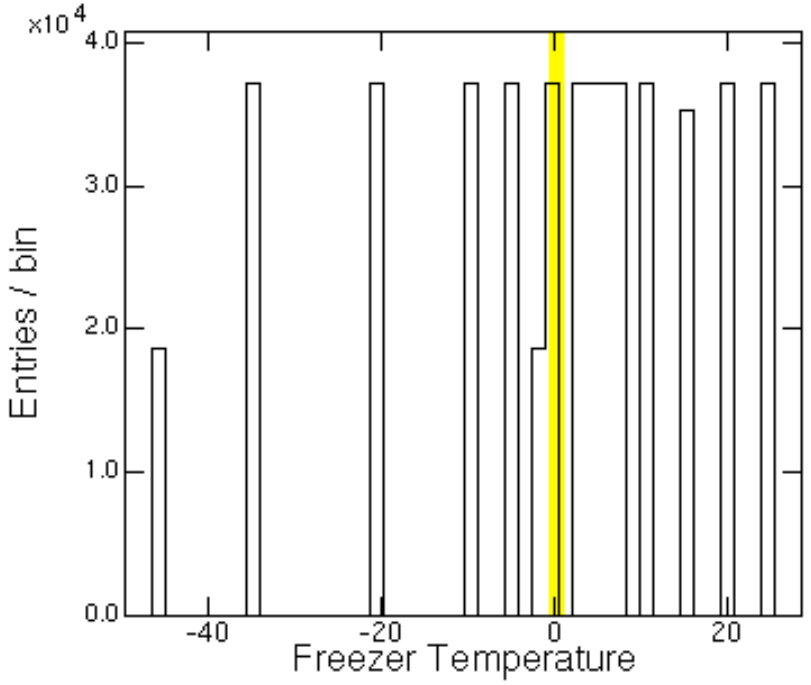
Total noise rate of sensor



Thermionic emission only







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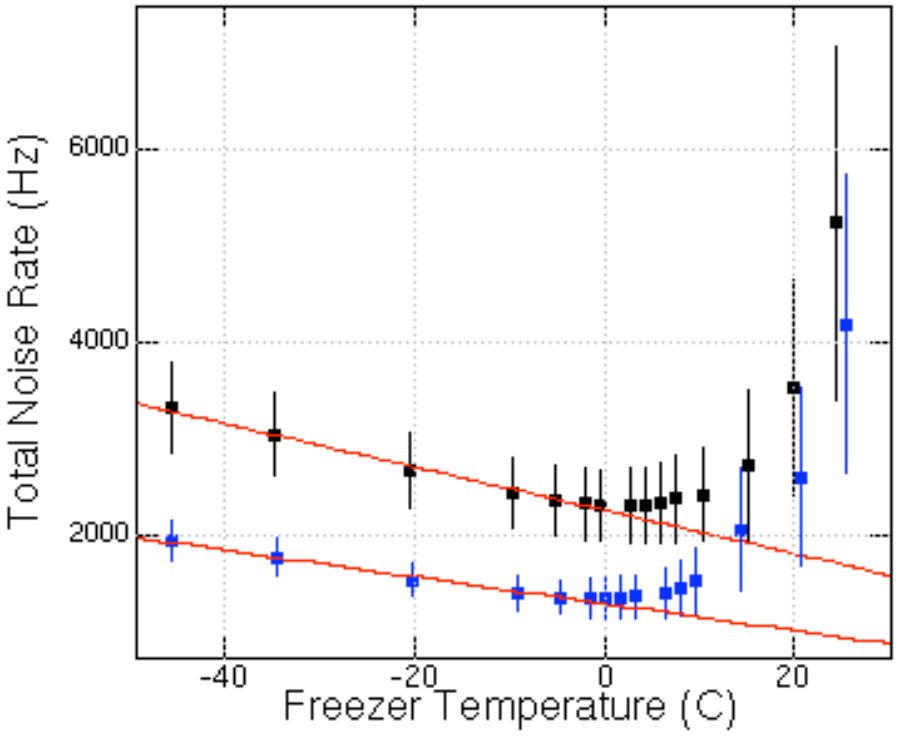
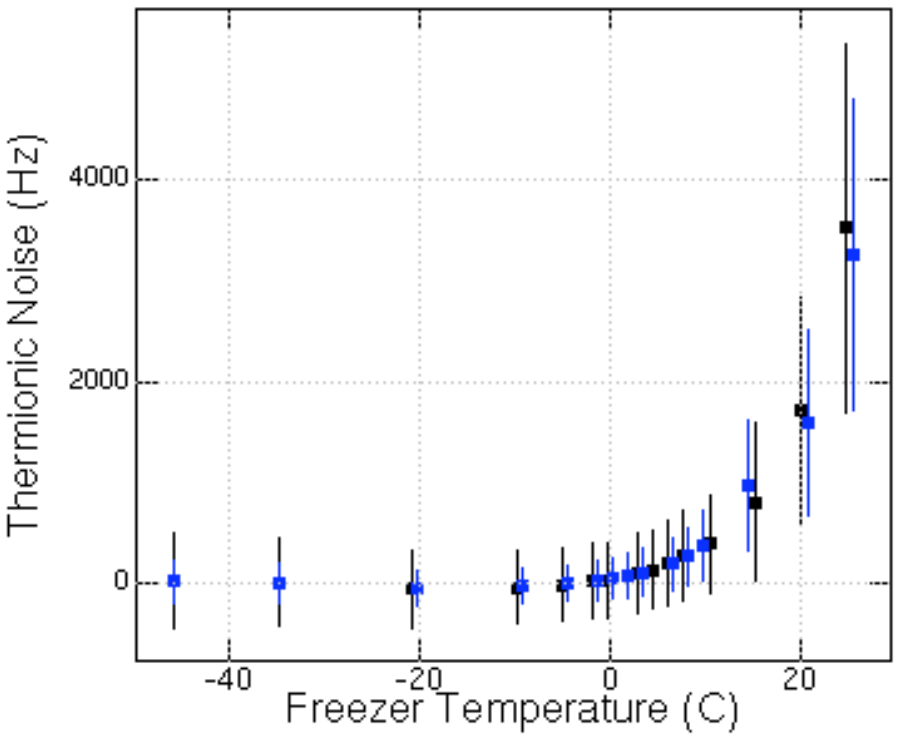
Scintillation noise with strong correlated noise components (late pulses)

Black: 0 microsecond deadtime

Blue: 6 microsecond deadtime





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HQE 10 inch PMT- Noise vs temperature

- At low temperatures the noise rates are dominated by glass of pressure housing (~85%) and glass of PMT (15%).
- Glass noise of PMT at high temperature ~300 Hz.
- Thermionic emission dominates at high temperatures
- Assuming a scintillation noise of 400 Hz for the PMT one can construct a corrected best estimate for the PMT only.
- Direct measurement of taped PMT only will give more precise data, but only few PMTs available.

Very preliminary
Correction to PMT rate.

T [°C]	DOM Rate [Hz]	corrected PMT rate [Hz]
0	2322	772
3	2317	790
6	2338	818
8	2388	845
11	2435	887
14	2738	1176
19	3539	1523
24	5245	2222

Higher photodetection efficiency

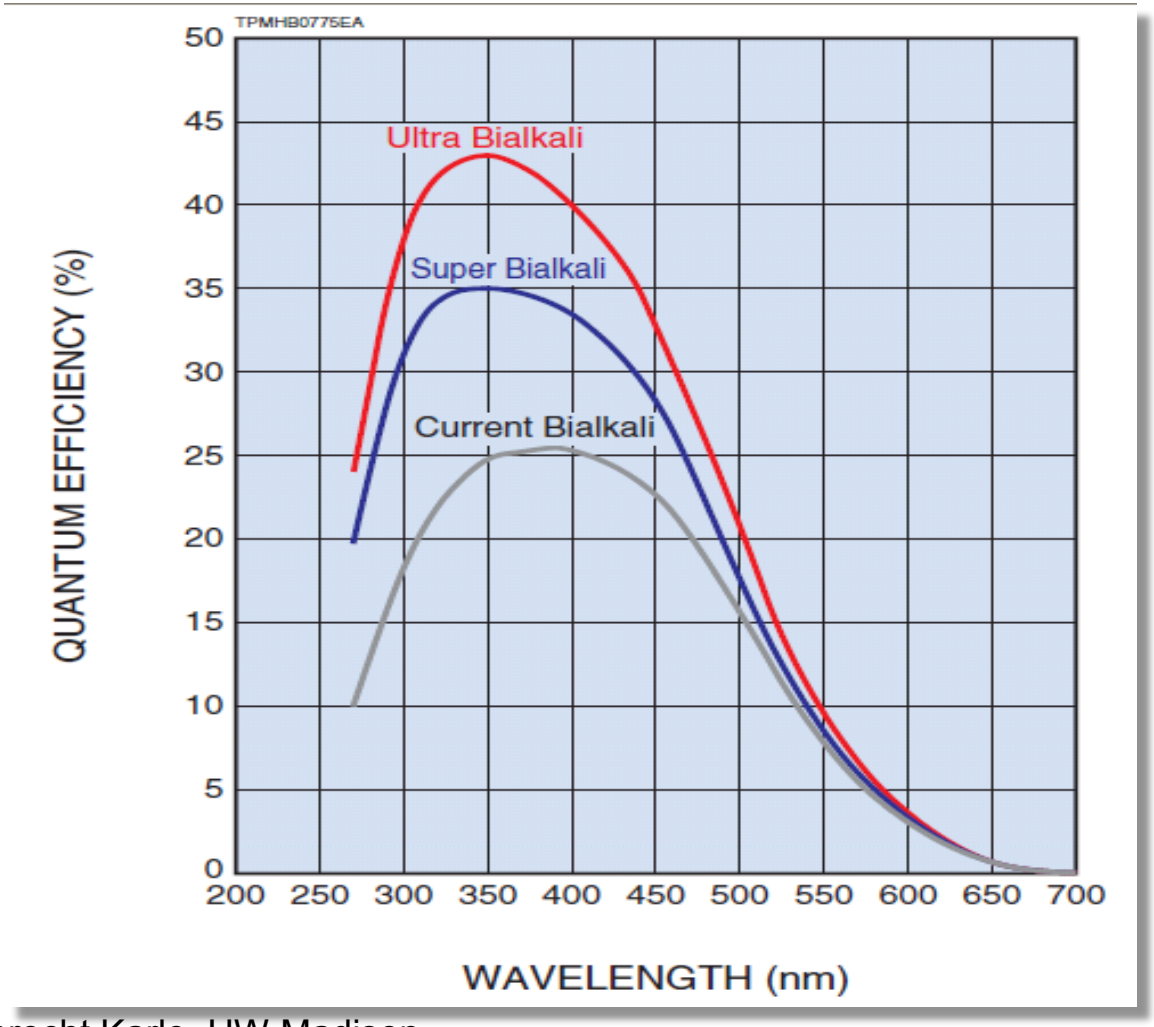
(photodetection efficiency: PDE = QE * collection efficiency, better figure of merit)

Higher quantum efficiency PMTs are a reality,

Hamamatsu has announced the Super-Bialkali photocathode:

Peak QE now 43%,

→talk by Nakamura-san from Hamamatsu at TIPP 2009

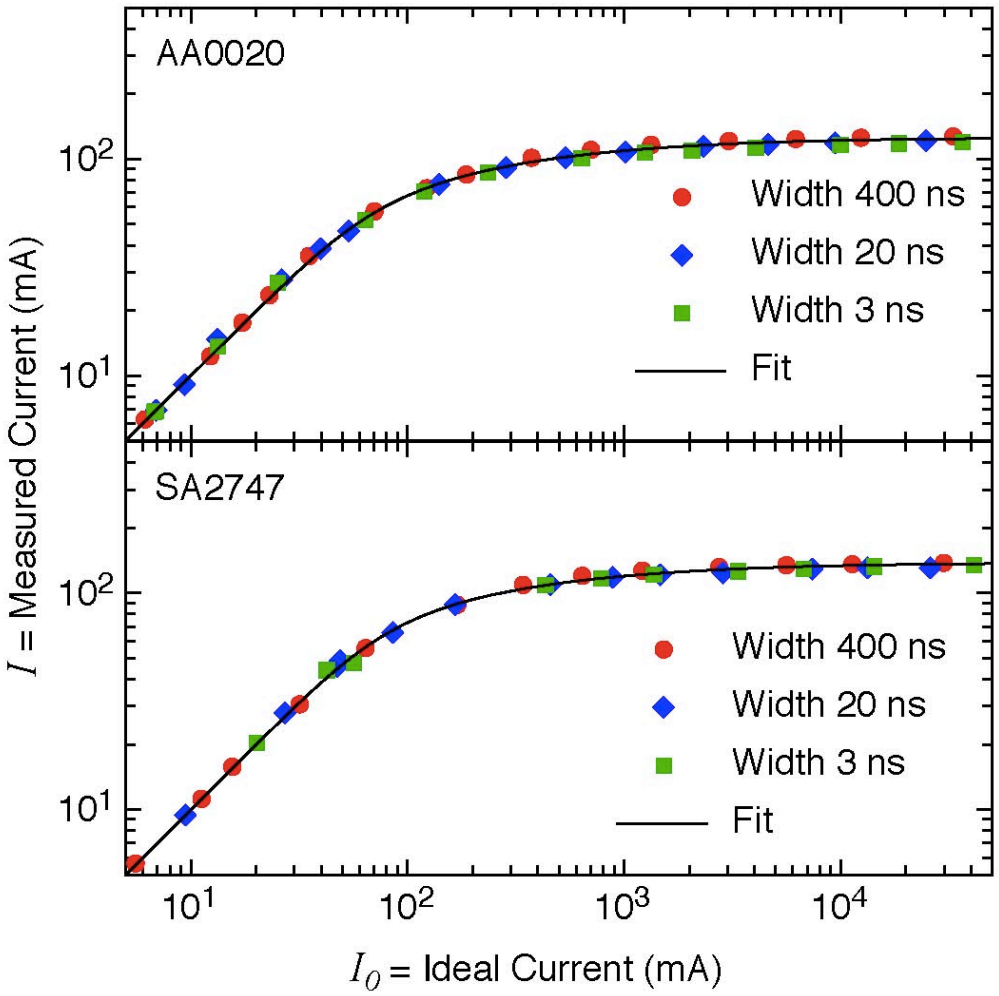


HQE PMT summary

- 78 HQE PMT tested, almost as many deployed in ice.
- All data look very good and within expectations.
- Sensitivity about 1.35 higher than standard PMT
- Noise rates of HQE PMT are well behaved, also at higher temperatures between 10 and 25C, with rates in the range of 1000 to 2500Hz.
- Appears reasonable to use HQE photocathode for preliminary planning assumption for any future large water Cherenkov detector.
- Superbialkali may become available for large area PMT

PMT saturation curve

a) Saturation at ~100 mA anode current.
b) Saturation behavior is the same regardless of the width of light pulse



Response to diode laser pulses

a) Main pulse
b) Secondary peak due to unusual electron trajectories
c) Pre-pulse (from first dynode, are below spe threshold. Gain ratio accordiing to first dynode gain)

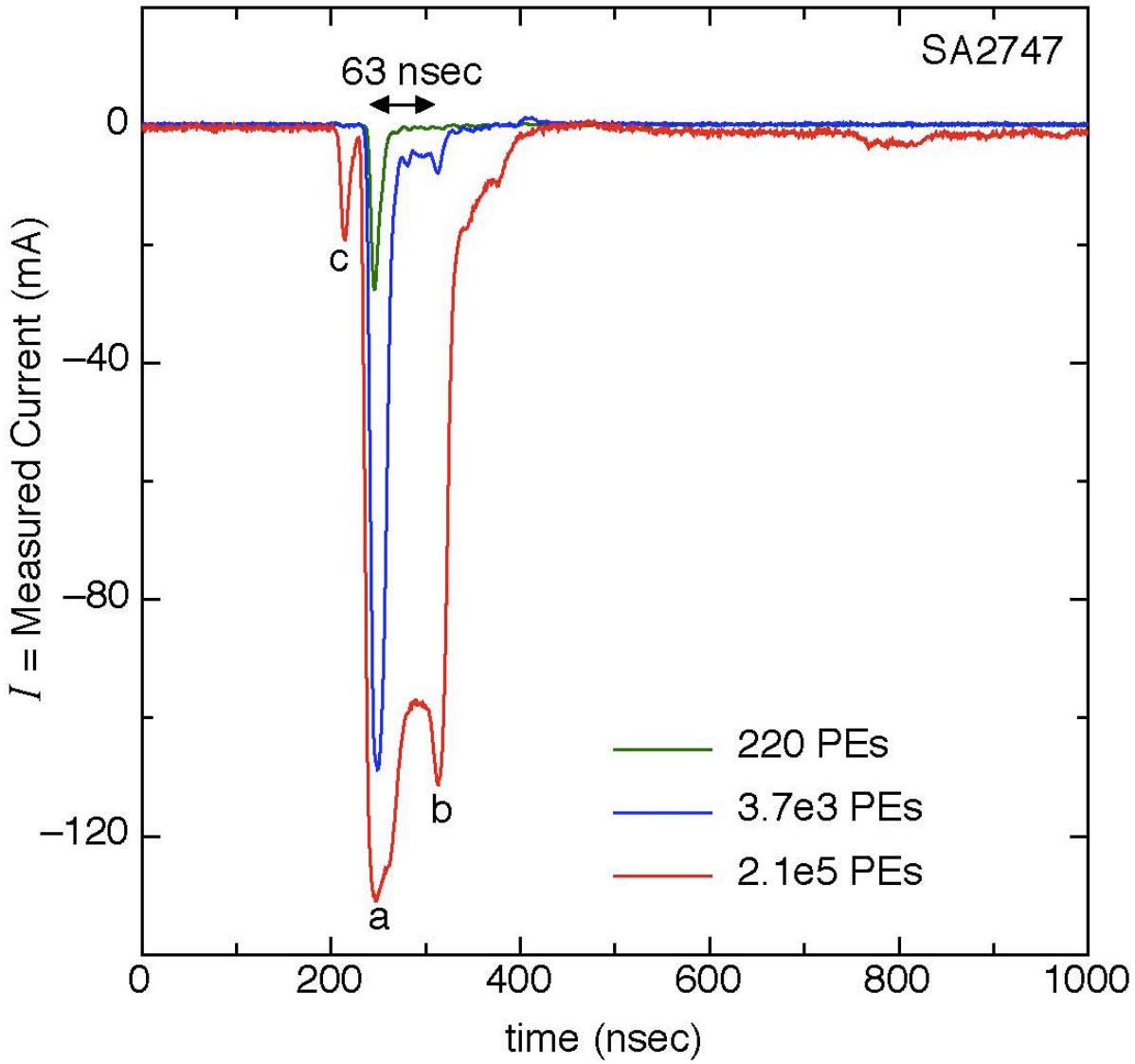


Fig. 16. Response of PMT to 3 ns (FWHM) light pulses with progressively higher-intensity: (a) main peak; (b) secondary peak due to unusual electron trajectories; (c) pre-pulse.